Embedded Instrumentation for Smart Munitions

David H. Lyon

Chief, Advanced Munitions Concepts Branch

Weapons and Materials Research Directorate
Army Research Laboratory

SOP of the Past

PAYLOAD IN

TELEMETRY IN

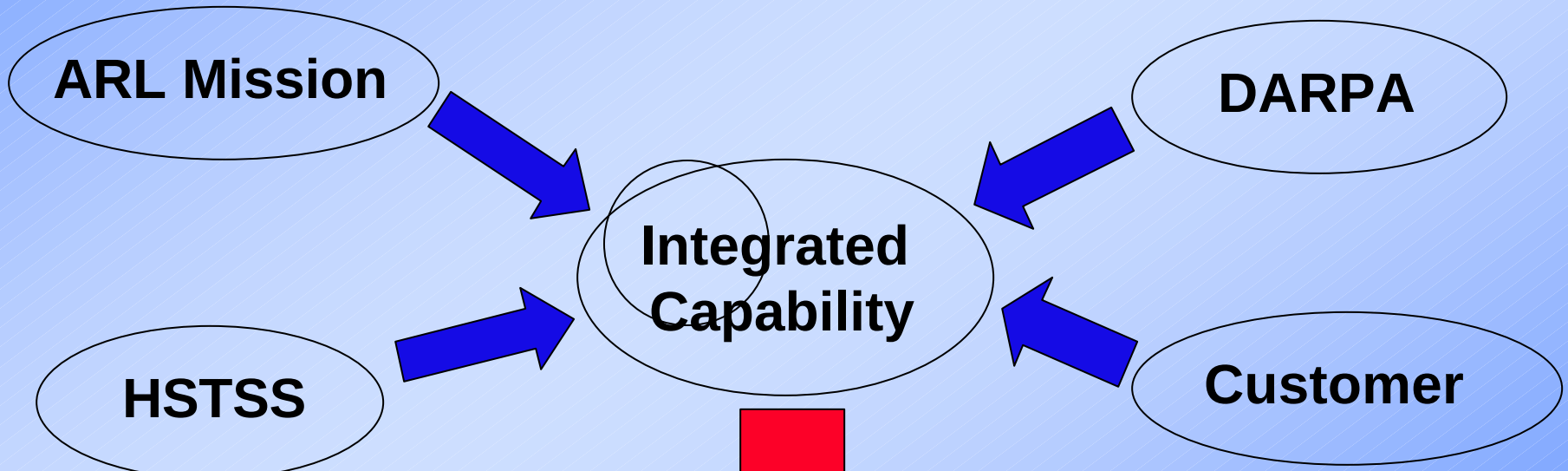
PAYLOAD OUT

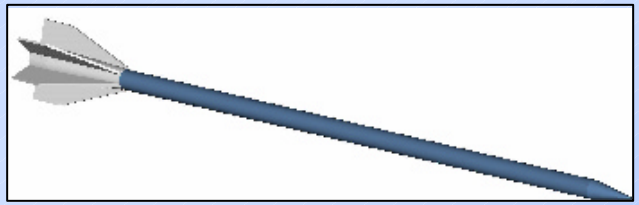
TELEMETRY OUT

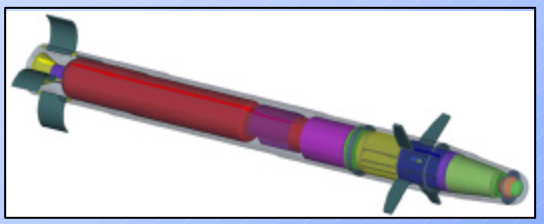
As we transition from dumb bullets to smart projectiles, the T&E requirements increase tremendously

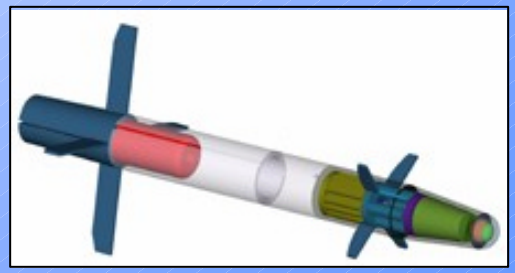
New Paradigm
Embedded Diagnostic Instrumentation

Single design, with embedded diagnostics, to cover all environments (cradle-to-grave)







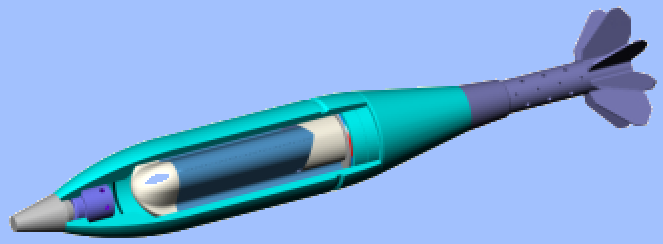


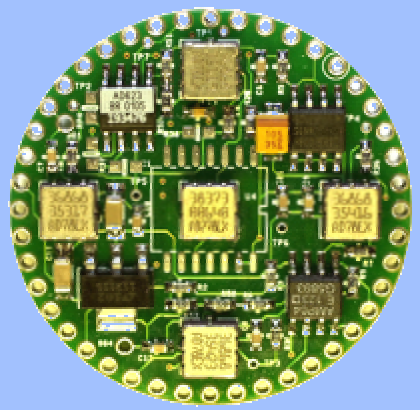
ARL Mission
Advanced G-Hardened G,N&C Suites

Objectives

Prototype advanced high-g components for smart munitions:

- **Develop low-cost sensor suites for gun-launch and high spin**
- **Develop next-generation telemetry components (embedded)**
- **Demonstrate techniques to measure roll, angular orientation, etc.**
- **Prototype devices to reduce Target Location Error (TLE)**





Pacing Technologies:

- **High-g microelectronics**
- **Embedded instrumentation**
- **COTS sensor integration**
- **Simulation algorithms**

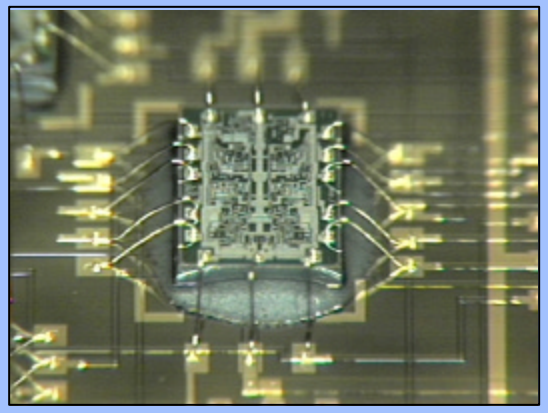
Warfighter Payoffs:

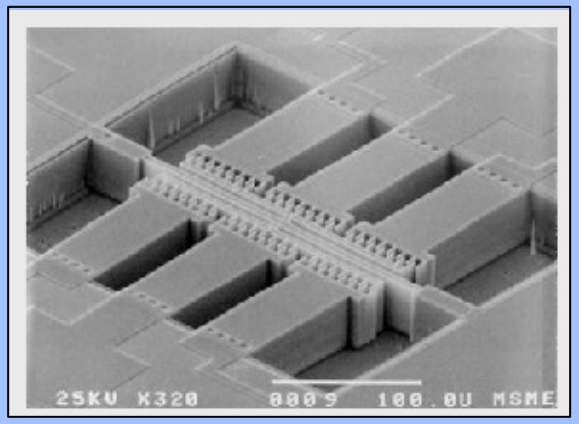
- **Increased first round hit**
- **Slash development time/cost**
- **Provide ground-truth for T&E**
- **Validated designs for FCS**

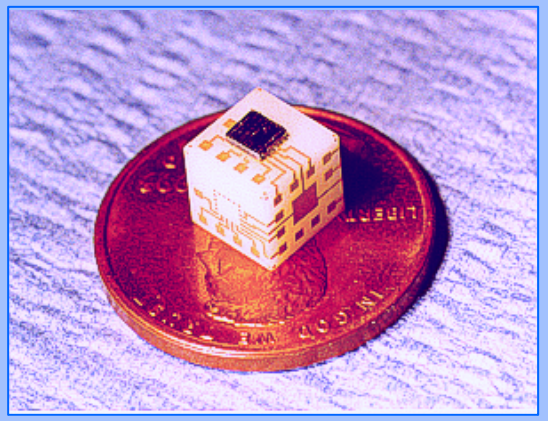
Hardened Subminiature Telemetry and Sensor Systems (HSTSS)

Goal: **Develop advanced instrumentation and packaging for the T&E of high-g, gun-launched smart munitions**

Approach: **Utilize COTS technology, leverage DARPA investments, use ARL as technical lead and systems integrator**







<u>Pacing Technologies</u>:

- **Design and procurement of die level comp.**
- **Advanced packaging technologies - MCM, Chip Stacking, Flip Chip**
- **MEMS based sensors**

<u>DoD/Warfighter Payoffs</u>:

- **Lower-cost and lower-risk development cycle for smart munitions**
- **Embedded diagnostics for seamless transition from R&D, Production, Life Cycle monitoring**

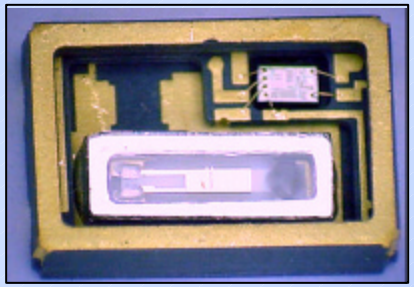
Reference Oscillator

Statek Crystal Reference Oscillator Requirements

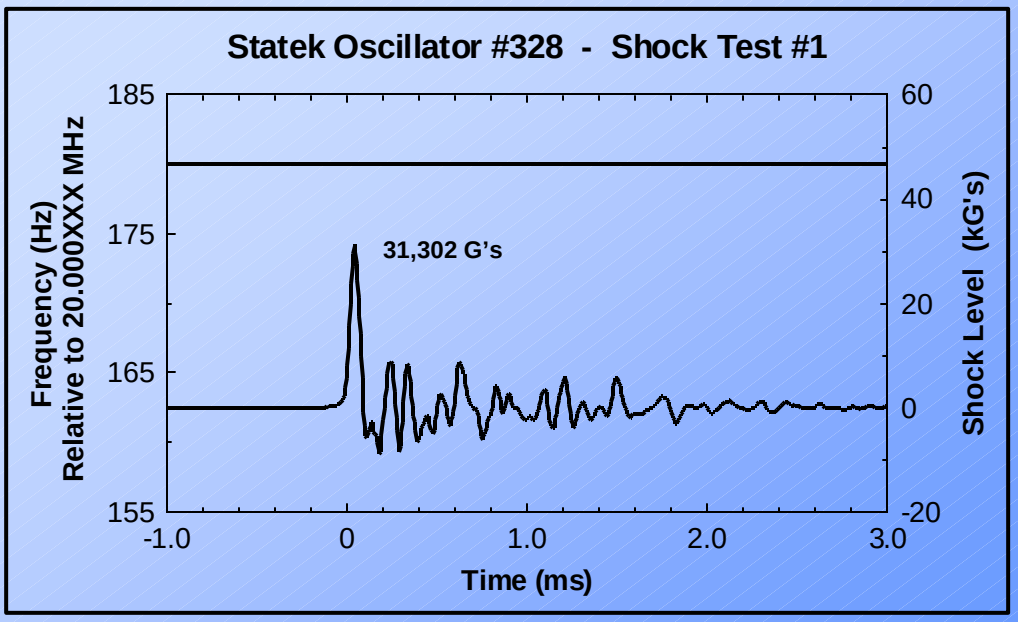
Nominal Output Frequency	20MHz	**Acceleration Sensitivity**	0.4Hz/G
Frequency Stability	+/- 20ppm	**Phase Noise**	-140dBc/Hz max at 100kHz
Output	Square Wave	**Jitter**	250ps max
Supply Voltage	3.0V (+/- 5%)	**Rise/Fall Time**	8ns max
Max Physical Size	350 x 300 x 150 mils	**Duty Cycle**	40% - 60%
Operational Temperature Range	-40 to +85degC	**Current Draw**	5mA max
Shock Ranges	500G, 30kG, 100kG	**StartUp Time**	10ms max

Crystal Resonator

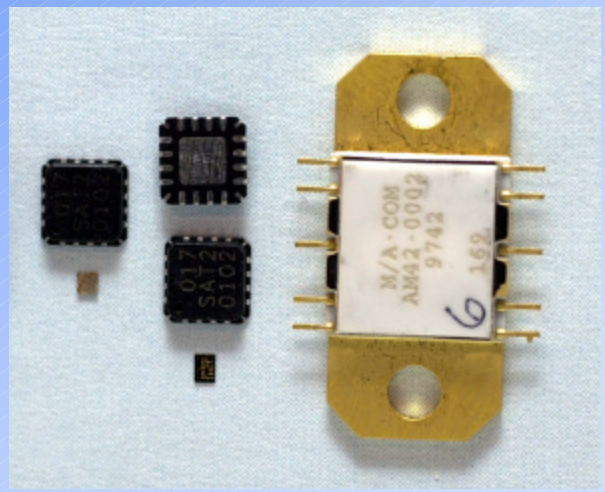
Oscillator

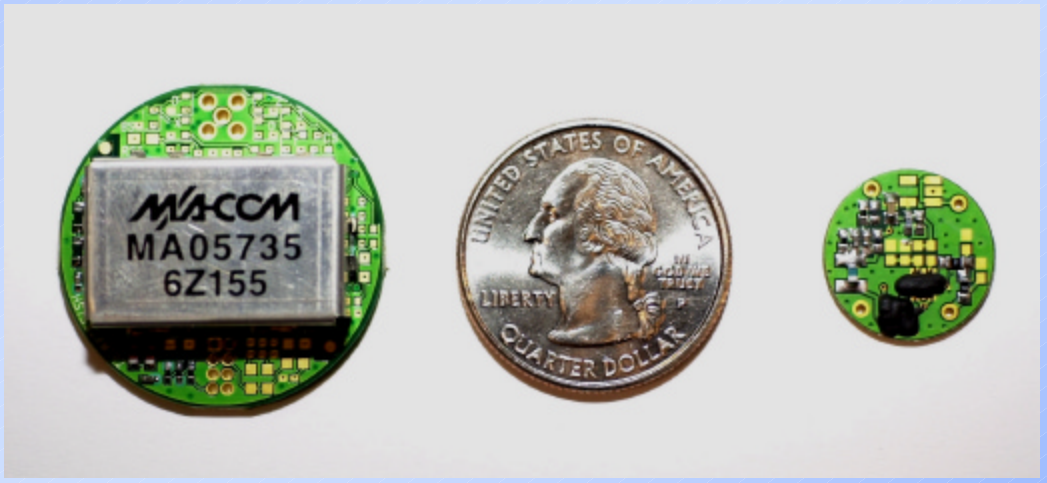


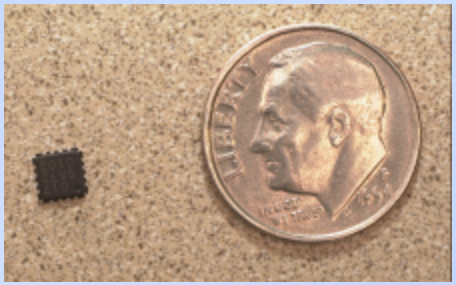
Crystal Resonator Mounted Inside Oscillator Package

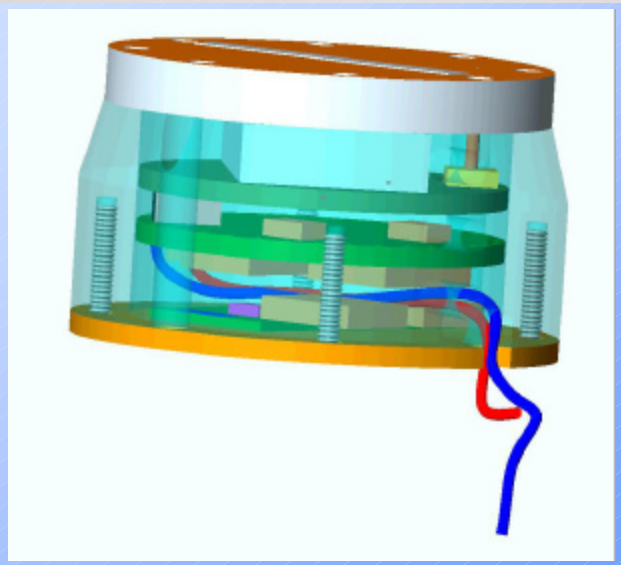


Transmitters









tyco Electronics MACOM

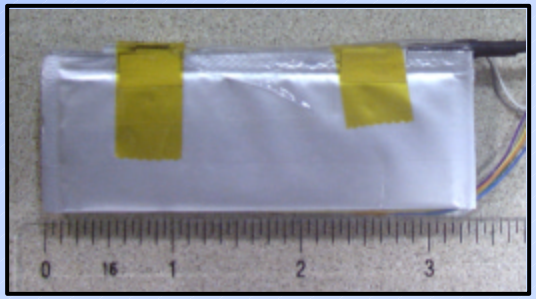
HSTSS Batteries

Ultralife Primary Li/MnO_2 Pouch Cell Batteries

Artillery Nose Fuze Battery

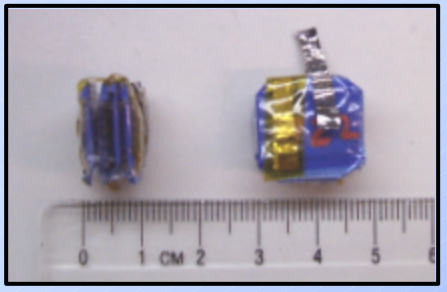
Nominal Voltage: 24V
Dimensions: 0.98” x 0.98” x 1.12”
Typical Discharge Current: 250mA
Minimum Runtime: 30 minutes to 12V

2.75” Rocket Battery



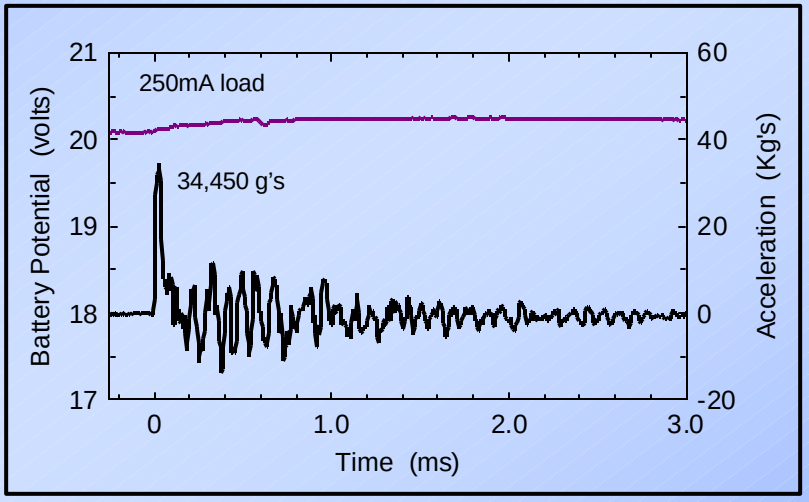
Nominal Voltage: 21V
Dimensions: 3.38” x 1.25” x 0.50”
Typical Discharge Current: 500mA
Minimum Runtime: 2.5 minutes to 12.5V

KE Projectile Tracer Well Battery

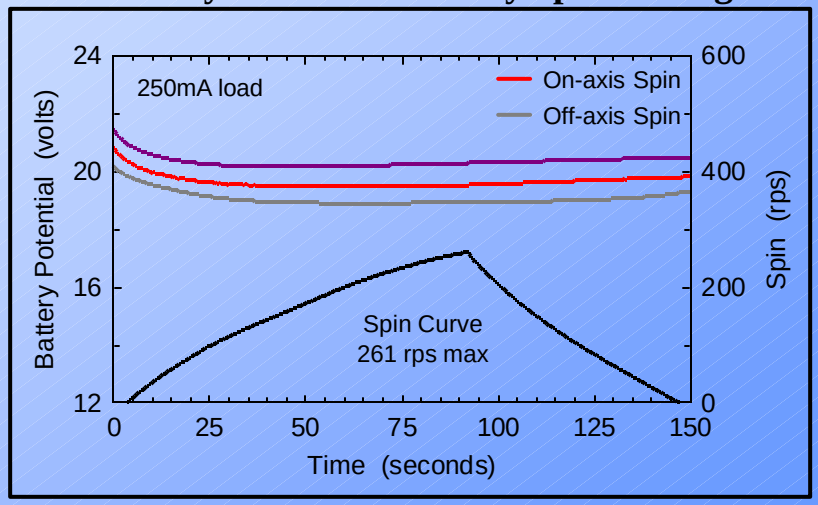


Nominal Voltage: 12V
Dimensions: 0.63” x 0.67” x 0.348”
Typical Discharge Current: 150mA
Minimum Runtime: 6 seconds to 6V

Artillery Nose Fuze Battery Shock Testing

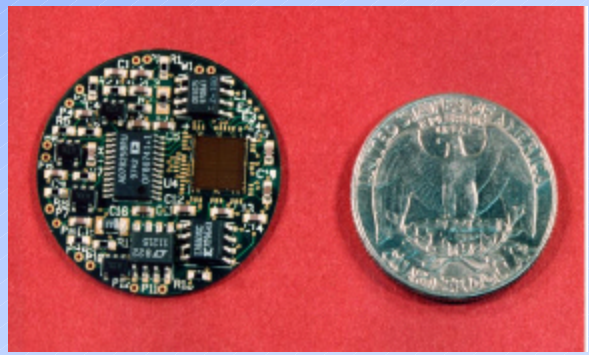


Artillery Nose Fuze Battery Spin Testing



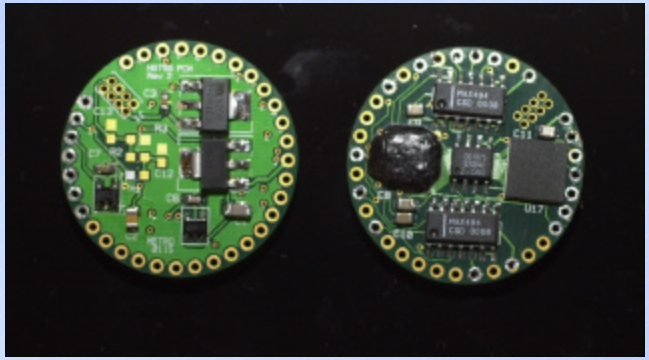
HSTSS Data Acquisition Solutions

- CPLD based PCM encoders developed at ARL
- FPGA and PIC based PCM encoders developed at NAWC



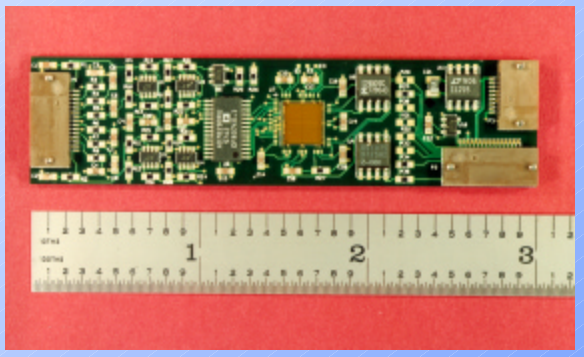
4 Channel/ 8 Bit

- 500 Kbps
- SR = 8.93KHz/ch
- 30 mA @ 5 V



8 Channel/ 12 Bit

- Up to 5 Mbps
- SR = 37.9 KSPS/ch
- 65 mA @ 5 V

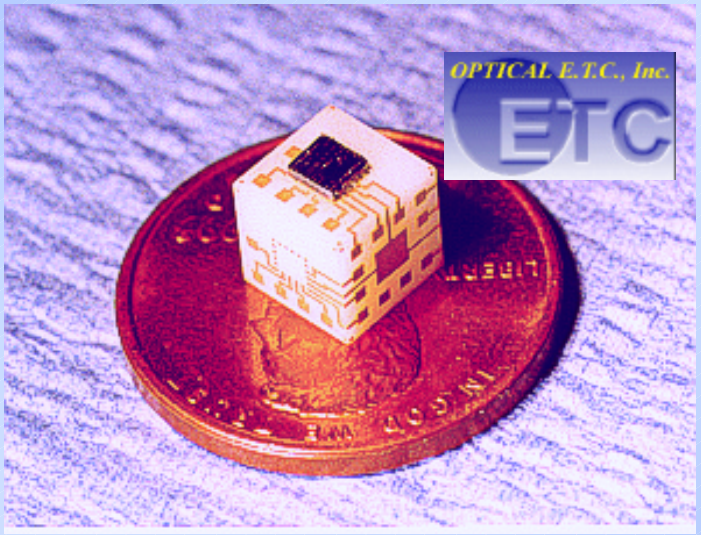


8 Channel/ 8 Bit

- 240 Kbps
- 1 ch sampled @ 10 KHz
- 7 ch sampled @ 2 KHz

HSTSS Sensor Development

- **Evaluate COTS MEMS technology for ballistic applications**
- **Develop process for qualifying MEMS devices**
- **Leverage DARPA & other service investments**

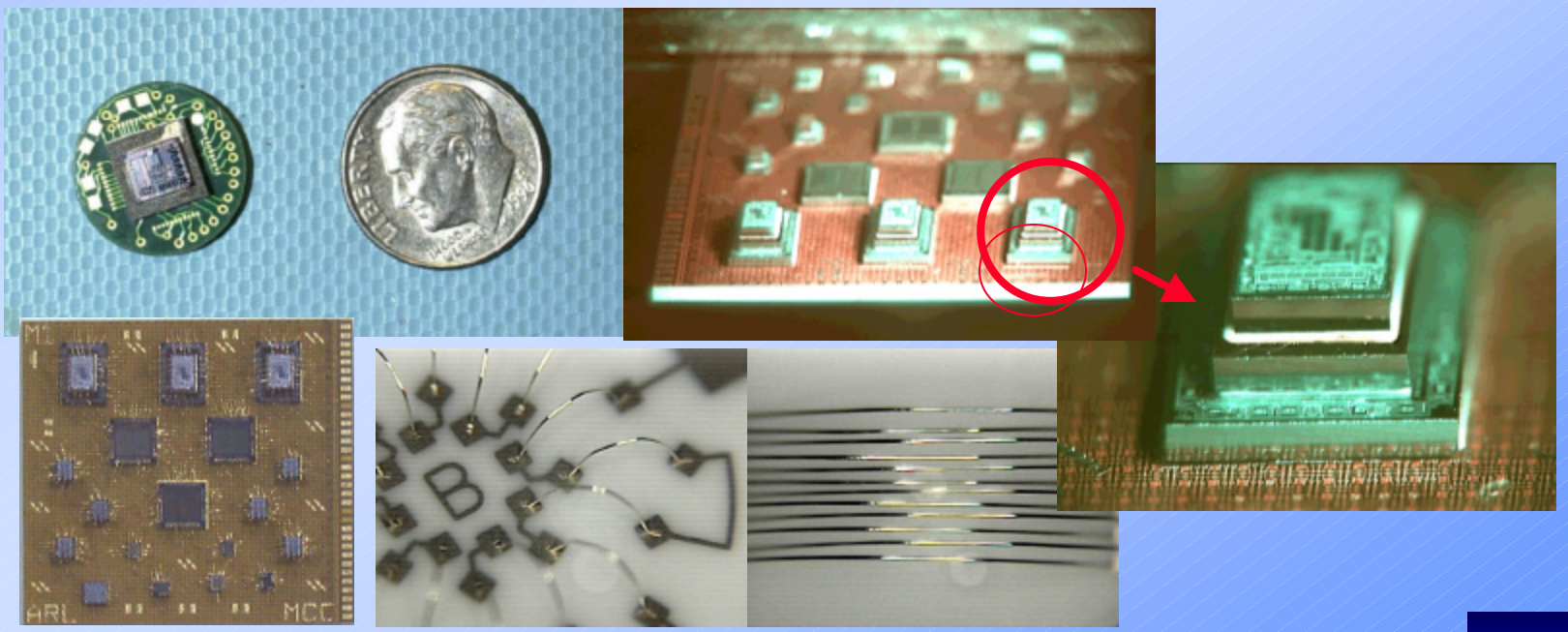


Optical E.T.C. Inc. **Air Force SBIR**

- **3 axis MEMS acceleration package**
- **2 accelerometers per chip (dual range)**
- **Flip Chip design**
- **Further package development**
- **Enhance accelerometer performance**

HSTSS
Advanced High-g Packaging

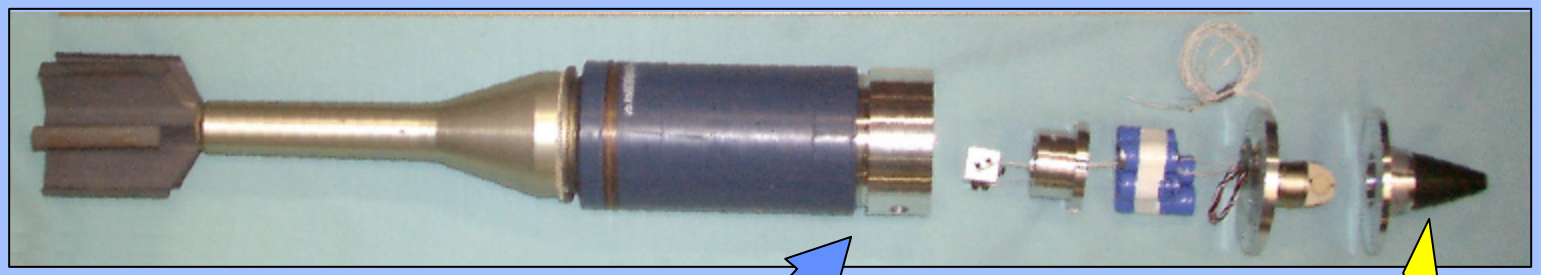
- Establish & qualify microelectronic assembly techniques for ballistic environments
  - **Establish boundaries**
  - **Adopt & modify commercial techniques**
  - **Address substrate materials, adhesives, interconnect, etc.**

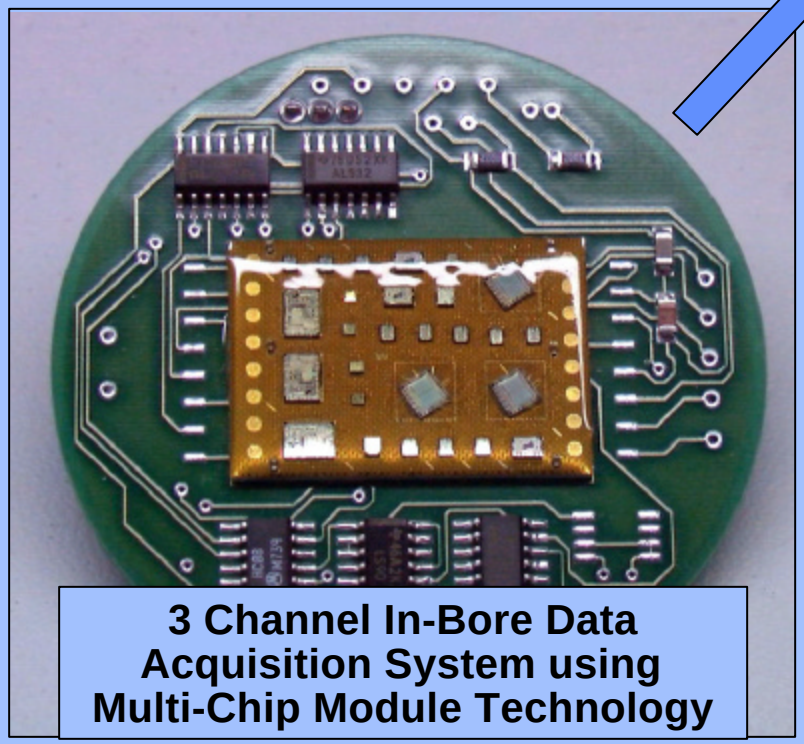


MCC

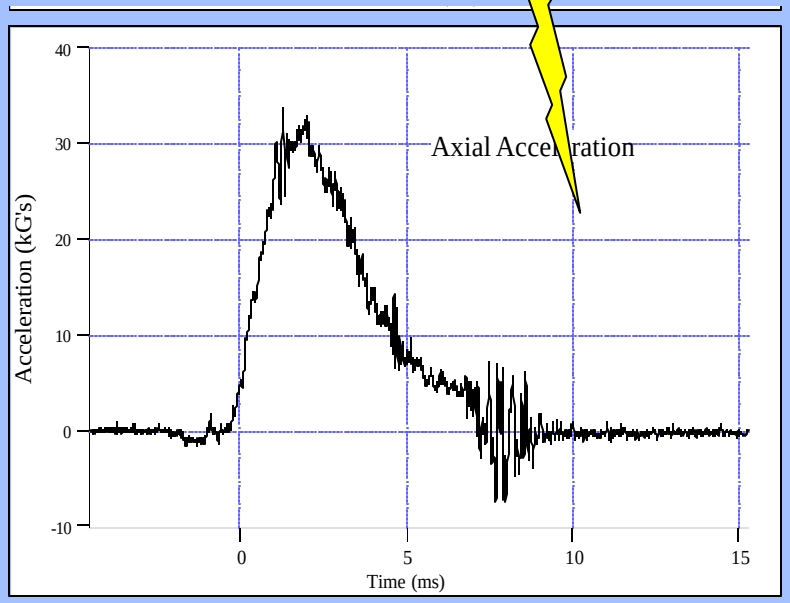
Very High-G Demonstrations

Supports FCS and AGS via In-bore and Free Flight Telemetry Capability





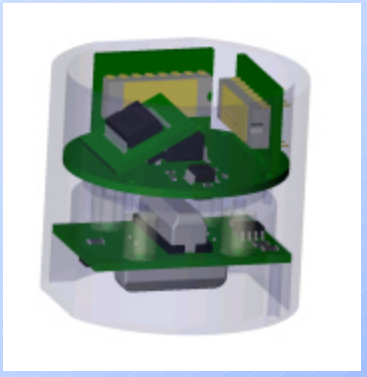
3 Channel In-Bore Data Acquisition System using Multi-Chip Module Technology



In-Bore Axial Acceleration

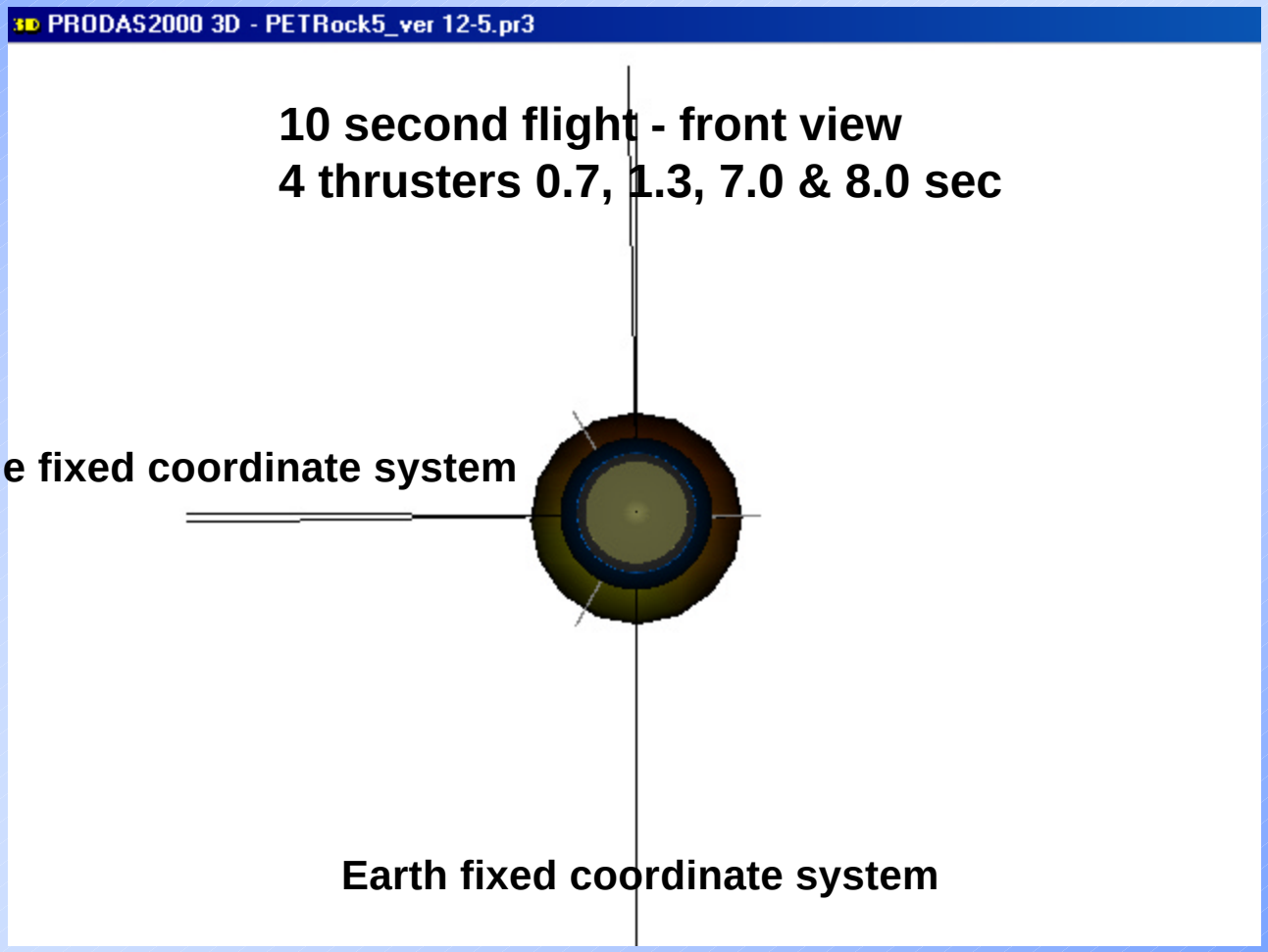
MCC

DARPA/ARL Hydra-70 with Impulse Thrusters



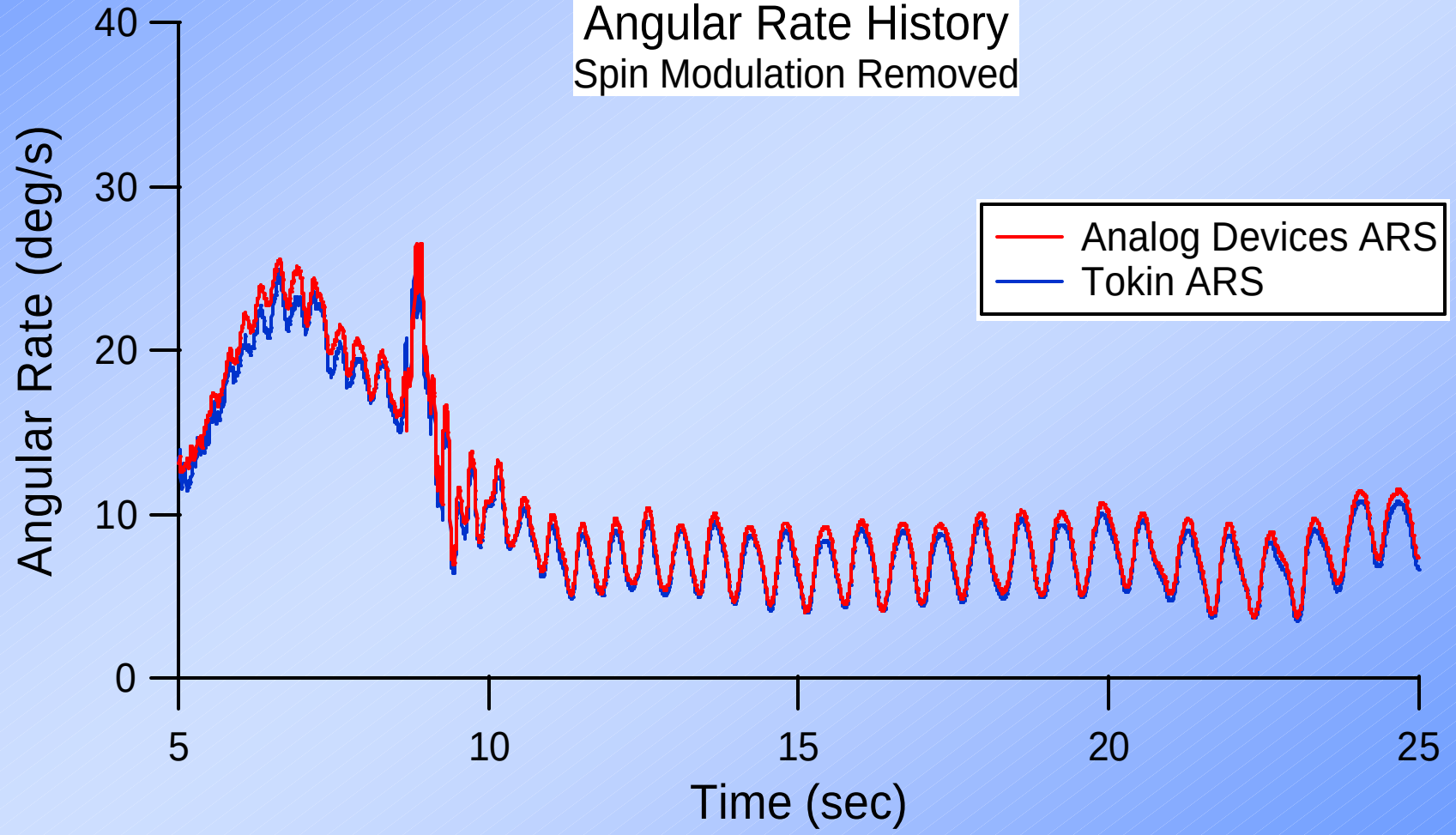
- Integrate MEMS angular rate sensors into IMU to control impulse thrusters
  - **TM multi-channel sensor data from angular rate sensors, accels., strain gages, etc.**
  - **Evaluate devices by comparing similar outputs**
  - **Simulate trajectory using PRODAS/BOOM**

Predicted Hydra-70 Trajectory
Impulse Thrusters



Angular Rate Sensors

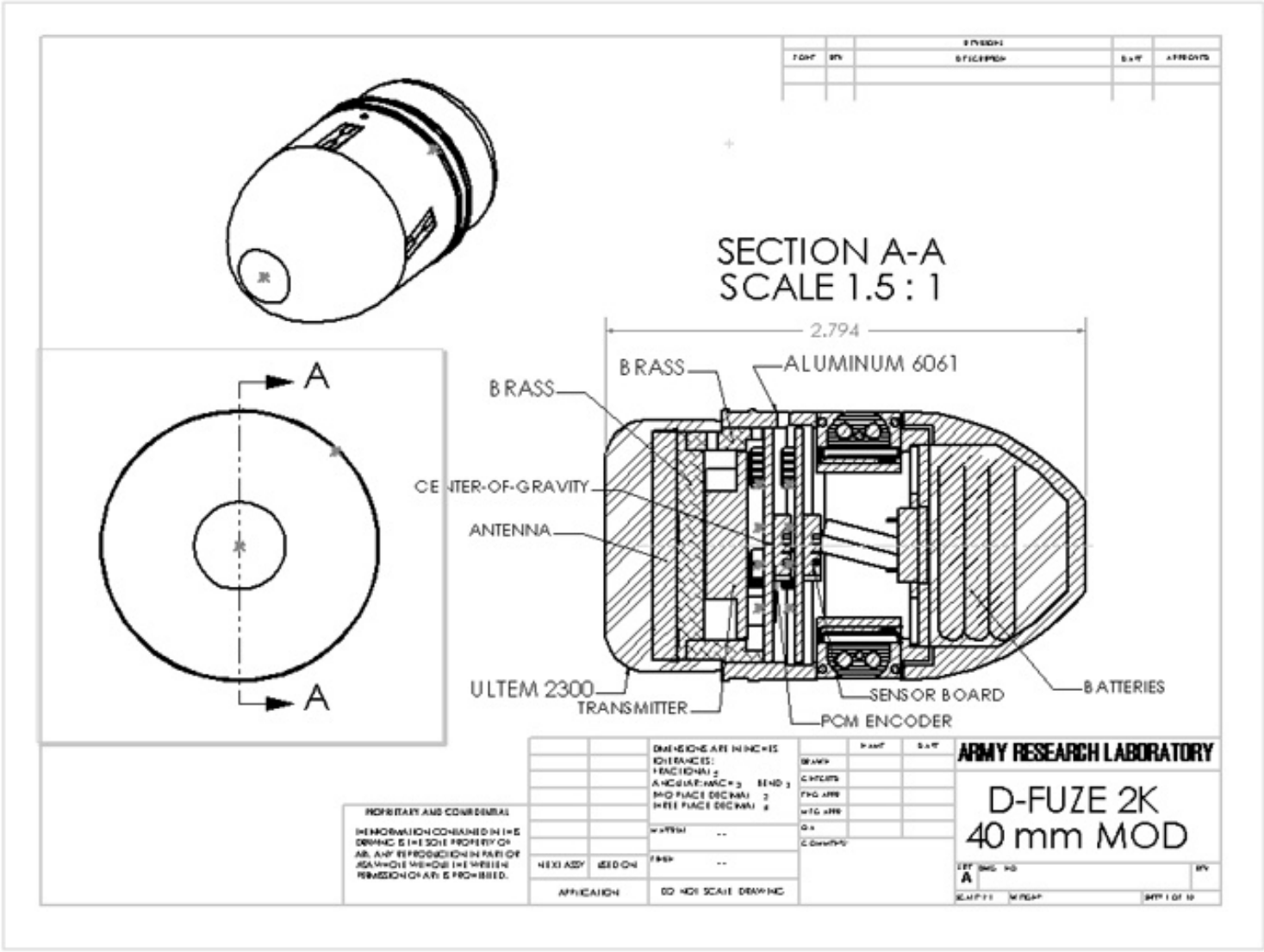
Orthogonal Pair



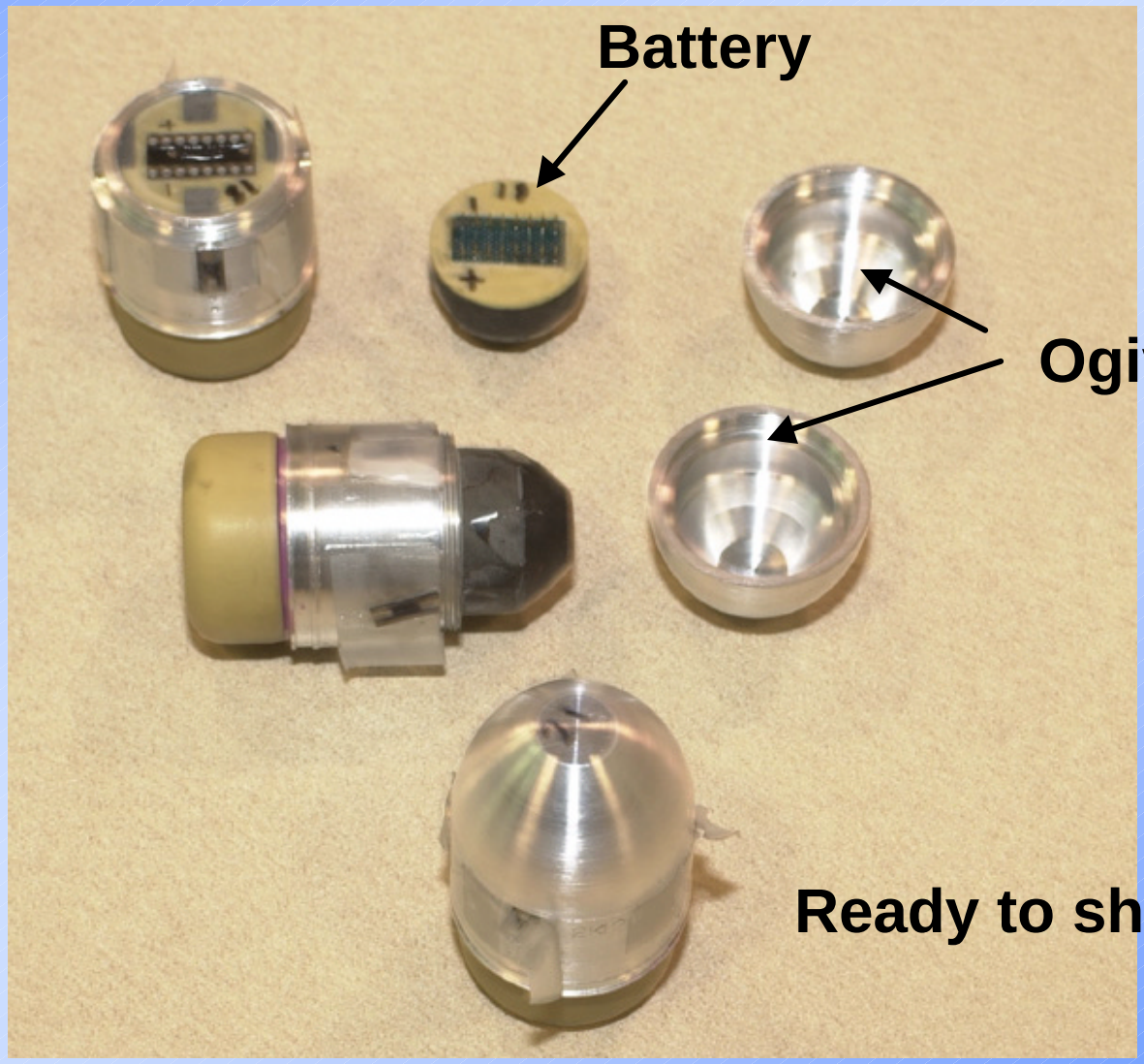
DARPA/ARL SCORPION Guided Projectile

- Integrate G,N&C on medium caliber munition
  - **40-mm grenade utilizing Micro Adaptive Flow Control to provide maneuver authority**
  - **Provide multi-channel sensor data from surrogate M203 projectile**
  - **Integrate antenna, transmitter, PCM encoder and battery with sensors**
  - **Acquire data using ground station**

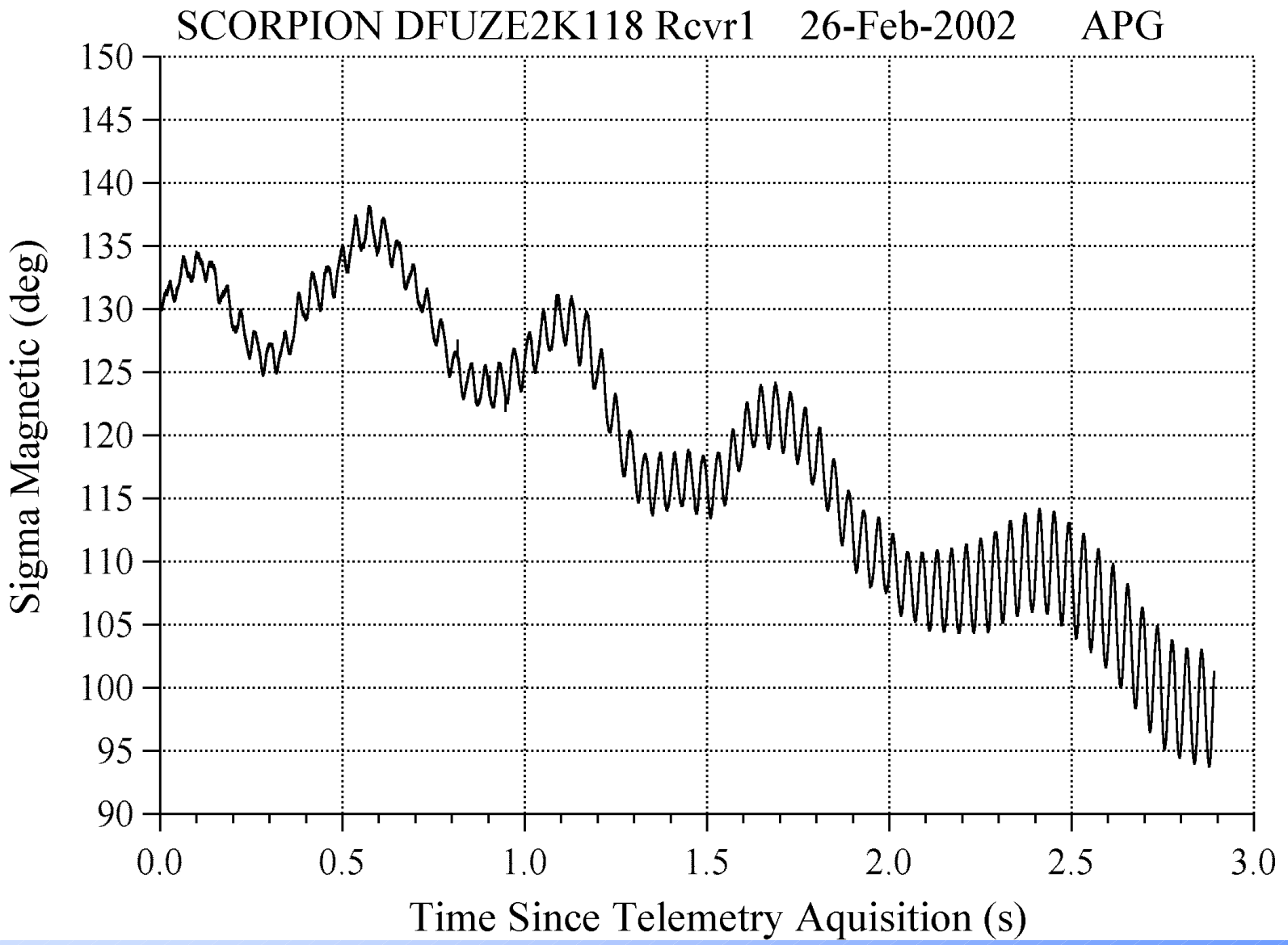
SCORPION TM
PROJECTILE LAYOUT



SCORPION TM
FLIGHT HARDWARE

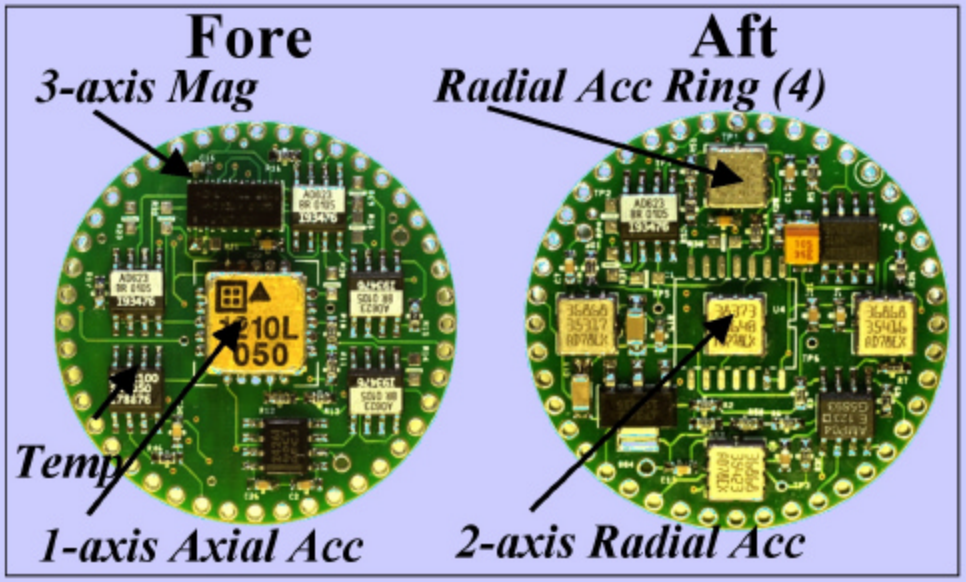


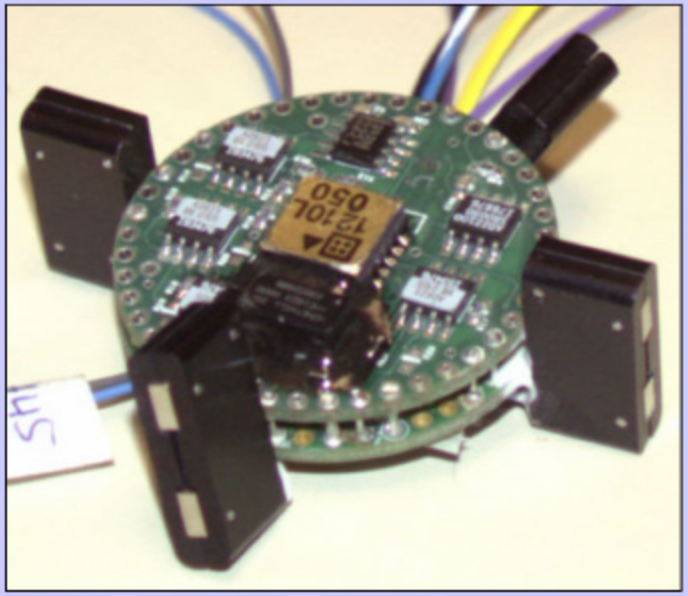
SCORPION SENSOR SUITE DATA



40mm Inertial Sensor Suite (ISS)

- 36 mm printed circuit board
- 9 measurement channels
- Uses low-cost parts
- High-g survivable





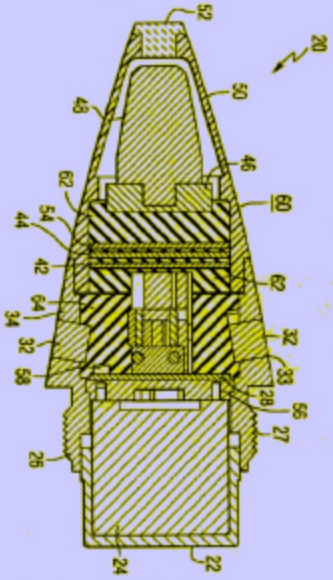
MEASUREMENT	Signal	PART	MAKER	SELECTABLE RANGES
1-axis Axial Acceleration	Acc I	SD1210	SDI	+/-5, 10, 25, 50, 100, 200, 10k* g's
2-axis Radial Acceleration	Acc J, K	ADXL278	ADI	+/-35, 70 g's
3-axis Magnetic Field	Mag I, J, K	HMC1023	Honeywell	+/-6 Gauss
Accel Ring Spin Rate	Spin	ADXL78 (4 ea.)	ADI	+/-35, 70, 120, 250 g's (0 - 70 Hz)
Solar Field Optical Sensors	Solar	SLIT (4 ea.)	ARL	
Temperature	Temp	AD22100	ADI	-50 to 150 degree C

ARL - Aeroballistic Diagnostic Fuze (DFuze)

- **Problem:** Ground-based instrumentation (i.e. radars, photos, and pressure gages) have limited capabilities.

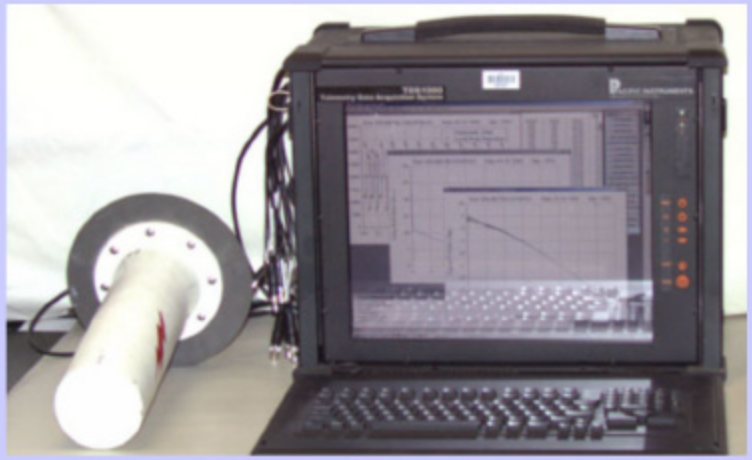
DFUZE 2001 – High-G Projectile-Borne Instrumentation System

Artillery Nose Fuse Replacement



(Patent US 6,349,652)

Portable Data Acquisition System



- Post-Flight processing
  - Quick Look - 6 minutes
  - Final Analysis - 1 month

- **Solution:** DFuze is a projectile-borne, non-intrusive method to verify flight performance, validate aerodynamics and maneuver authority.

Summary

- Requirements for enhanced capabilities continue to evolve
  - **Embedded diagnostics coupled with telemetry**
- Significant progress through multiple efforts (ARL, HSTSS, DARPA, PMs)
  - **Leveraging approach to maximize return**
  - **Constantly shrinking volume and cost**
- Future efforts center on extending the envelope
  - **Medium and small caliber systems**
  - **EM and ETC launch environments**